2023

PHYSICS — HONOURS

Paper : CC-6

(Thermal Physics)

Full Marks : 50

The figures in the margin indicate full marks.

Candidates are required to give their answers in their own words as far as practicable.

Answer ***question no.*** 1 and ***any four*** questions from the rest.

1. Answer ***any five*** questions : 2×5

(a) An ideal gas expands (i) isothermally, and (ii) adiabatically to twice its initial volume from the same initial state. In which case does the gas do more work? Explain with the help of indicator diagram.

(b) Determine the efficiency of a Carnot engine with the help of T-S diagram.

(c) Under what condition equilibrium of a system is determined by the minimum of Gibbs free energy?

(d) One cylinder contains Helium gas and another contains Krypton gas at the same temperature. Draw their relative velocity distributions on the same diagram.

(e) Considering $\frac{dV}{V}$ an exact differential show that $-\left(\frac{\partial \kappa_T}{\partial T}\right)_p = \left(\frac{\partial \beta}{\partial p}\right)_T$, where κ_T and β are isothermal compressibility and coefficient of volume expansion respectively.

(f) Calculate the ratio of rms velocities of Hydrogen and Oxygen molecules at 0°C.

(g) What fraction of gas molecules will have free paths lying within λ and 2λ, where λ is the mean free path?

2. (a) Write the conditions for a thermodynamic process to be reversible.

(b) The equation of state of an ideal elastic substance is given by

$$F = KT\left(\frac{L}{L_0} - \frac{L_0^2}{L}\right),$$

where F is the tension, K is a constant, T is temperature, L_0 is the value of L (length) at zero tension. Find an expression for the work required to change L from L_0 to $\frac{L_0}{3}$ quasistatically and isothermally.

(c) Assuming air to be an ideal gas find an expression for variation of temperature of atmosphere with altitude. 2+4+4

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3. (a) Prove that no heat engine operating between two temperatures ($T_1 > T_2$) can be more efficient than a Carnot engine operating between the same two temperatures.

   (b) Using Clausius inequality show that in any thermodynamic process entropy of the universe can never decrease.

   (c) Two identical bodies of constant heat capacity at temperatures T_1 and T_2, respectively, are used as heat reservoirs for a heat engine. If the bodies remain at constant pressure and undergo no change of phase, show that the maximum amount of work obtainable is $W = C_P\left(T_1 + T_2 - 2\sqrt{T_1T_2}\right)$.

   4+3+3

4. (a) Prove that $\left(\frac{\partial U}{\partial V}\right)_T = T\left(\frac{\partial P}{\partial T}\right)_V - P$. Calculate $\left(\frac{\partial U}{\partial V}\right)_T$ for a van der Waals' gas.

   (b) Prove that $C_P - C_V = T\left(\frac{\partial P}{\partial T}\right)_V\left(\frac{\partial V}{\partial T}\right)_P$. Show that for water at 4°C, $C_P = C_V$.

   (c) Derive the expression for the change in temperature of a paramagnetic substance undergoing cooling process by adiabatic demagnetization. (2+2)+(2+1)+3

5. (a) Prove the relations, (i) $TdS = C_V dT + T\left(\frac{\partial P}{\partial T}\right)_V dV$, (ii) $U = \left[\frac{\partial\left(F/T\right)}{\partial\left(1/T\right)}\right]_V$.

   (b) What are the characteristics of a first-order phase transition? Derive Clausius-Clapeyron's equation for first-order phase transition.

   (c) The rate of increase of vapour pressure of steam at 100°C is 3.68×10^4 dyne.cm^{-2}.°C^{-1}. If one gram of steam occupies a volume of 1674 cc, what is the specific latent heat of vaporization? (2+2)+(1+3)+2

6. (a) The probability of a gas molecule having velocity lying between u and $u + du$ in a given direction is,

   $$f(u)du = Ae^{-bu^2}du, \text{ where } A = \sqrt{\frac{m}{2\pi kT}} \text{ and } b = \frac{m}{2kT}.$$

   Using the above derive Maxwell's speed distribution formula.

   (b) Calculate average value of u^2.

   (c) Which physical quantity is transported in case of viscosity of a gas? Explain how the coefficient of viscosity of an ideal gas depends on temperature. 4+3+(1+2)

7. (a) Write the van der Waals' equation of state for n mole gas occupying volume V. Plot $P - V$ diagram of van der Waals' gas at temperatures $T_1 < T_C$ and $T_2 > T_C$.

   (b) Determine critical constants of a real gas obeying van der Waals' equation of state.

   (c) Write the Fourier equation for rectilinear flow of heat along a metallic bar. Hence write the steady state equation and solve it when there is no radiation loss. (1+1)+4+(1+1+2)